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ABLATION OF HUMAN DENTAL ENAMEL USING THE Cu-HBr LASER: A PILOT-STUDY

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ABSTRACT

Dental hard tissues are biological translucent ceramics and the interest in investigations on copper laser processing of these materials aims the wide potential of clinical applications of this laser. In this pilot-study, cavities were generat*ed in human dental enamel without photo-absorbers, using focused green line radiation from a Cu-HBr laser (0.10±0.02 mm of spot), and decreasing exposure times, from 2.5 s to 0.1 s, in steps of 0.5 s, and from 0.45 s to 0.20 s, in steps of 0.05 s. Optical micrographs showed that the edges of the cavities were formed by melted and re-solidified dental enamel. Carbonization was outlining some edges and a few deep and long thermal cracks were observed radial to the cavities. The smallest mean exposure time (over sixteen experiments) for cavity generation was 0.30±0.03 s. Experimental evidences suggest that cavities were generated by a thermal process, due to the overlap of consecutive pulse energy deposition, in a short time interval, at the same spot of the sample.*

1. INTRODUCTION

Dental enamel and dentin are ceramic materials with small contents of water and organic compounds. They are thermal insulators and optically translucent (weak absorbers and high scatterers of visible radiation).
As far as copper laser processing of ceramics is concerned, cutting is clean and crack free [1]. For transparent materials, the copper laser generates cavities with high aspect ratios and walls of good quality [2].
Investigations on laser processing of biological translucent ceramic materials provide insight on the mechanisms of laser-tissue interaction that are important to the development of potential clinical laser applications and the determination of the laser ablation threshold and of the heat affected zone is usually one of the first steps towards this direction. In low power or in high penetration clinical applications, laser parameters should be kept always below the ablation threshold.
Yamada *et al*. [3] reported on ablation in human dental hard tissues using the green line of a copper vapour laser. In their study, laser ablation was achieved only if the dental tissues were covered with a thin layer of a photo-absorber (red or black ink).
In our previous work [4], cavities were generated in human dental enamel using the 510 nm line of the HyBrID (Hydrogen Bromide In Discharge) copper laser [5] (the same wavelength as Yamada *et al.*), but without photo-absorbers. The extension of the thermal damage and the structural and morphological differences between fused and non-fused dental enamel was evaluated by atomic force microscopy.
Following on from our previous work, a pilot investigation was performed to determine the threshold for cavity generation in human dental enamel without photo-absorbers, using decreasing exposure times of the 510 nm line radiation from the Cu-HBr laser.

2. MATERIALS AND METHODS

Figure **1** shows a schematic diagram of the experimental setup. The Cu-HBr laser utilized was built at the Instituto de Estudos Avançados [5,6]. An optical filter F was set into the laser beam pathway to reflect the yellow and transmit the green radiation. A lens f with 50 cm of focal length focused the beam to a spot size of (0.10±0.02) mm on the sample surface. An electronic shutter c was also placed in the beam pathway to control the exposure time. The distances d_f and d were 46.5 cm and 1 cm, respectively. The laser was set up to emit pulses with 28 ns of duration, 6.0 J/cm^2 per pulse at the green line (216 MW/cm^2 of peak intensity), and 14.1 kHz of repetition rate.

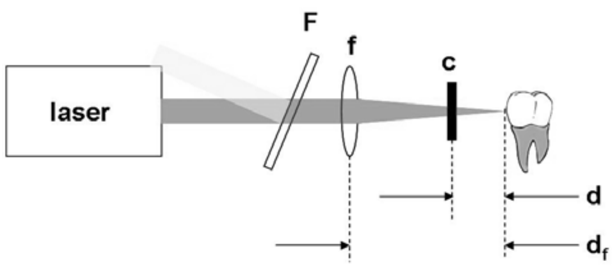

Figure 1 - Schematic diagram of the experimental setup where F is an optical filter, f is the focusing lens, c is an electronic shutter, and d_f and d are the distances from the focusing lens and from the shutter to the tooth surface.

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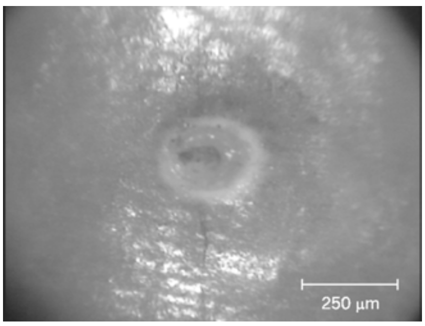
The two most plane faces of eight non-erupted and freshly extracted third-molars were chosen as targets. A two axis positioning stage allowed the sample to be moved horizontally and/or vertically after each shutter shot. The shutter open time (exposure time) varied decreasingly from 2.5 s to 0.1 s, in steps of 0.5 s, and from 0.45 s to 0.20 s, in steps of 0.05 s. Surface damages on the sixteen enamel surfaces were evaluated by reflected unpolarized light microscopy.

3. RESULTS AND DICUSSION

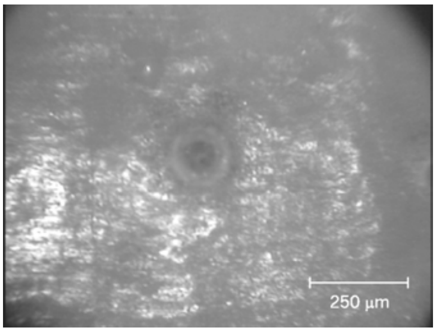
Figure 2 presents some light micrographs, showing representative cavities generated on the surface of the human dental enamel by the Cu-HBr laser and the respective exposure times. It can be clearly observed that the edges of these cavities were formed by melted and re-solidified enamel and carbonization is outlining some edges. In Fig. 2 (a), some deep and long thermal cracks are also found radial to the cavity. In Fig. 2 (f), no damage was found.

From the micrographs, no relation could be set between cavity diameter and laser exposure time. However, it was found that the smallest mean exposure time (over sixteen experiments) that still promotes cavity formation was 0.30±0.03 s. That means a cavity was not generated along a single laser pulse, like in conventional laser ablation processes with nanosecond duration pulses [7]. Probably, the approximately 4230 laser pulses focused onto the same spot induced a cumulative effect due to the overlap of consecutive pulses. Each laser pulse had deposited energy into the dental enamel that was instantaneously transformed into heat. As the dental enamel melts at 1280°C [8], the threshold exposure time most likely corresponds to the time necessary to the amount of heat generated exceed the diffusion capability of the tooth, leading to a thermal process of ablation (melting and evaporation) in the dental enamel.

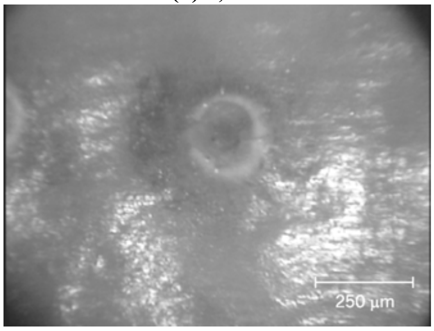
An additional experiment was carried out, aiming to investigate this cumulative effect: two samples had one unique site irradiated with three consecutive shutter shots of 0.1 s of exposure time and 1.0 s of inter-shot time. Examining the surface by light microscopy, no damage was detected in both samples. Next, this experiment was repeated with four, five and ten shutter shots. Even so, no apparent changes were observed. It was concluded that the successive pulse energy deposition and heat conversion should take place in a short time interval, compared with the heat diffusion times.



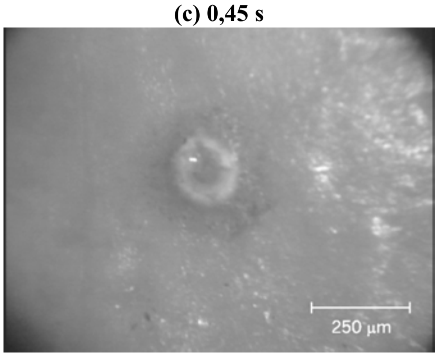
(a) 0,80 s



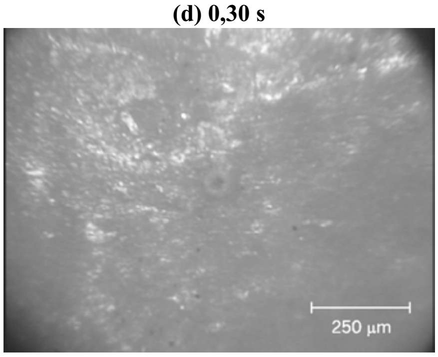
(b) 0,50 s



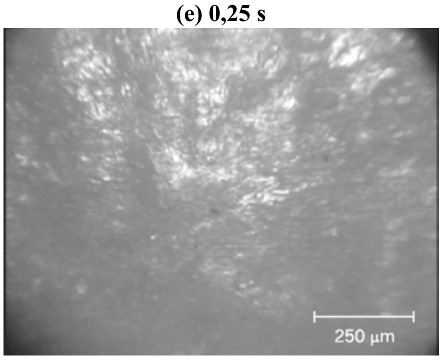
(c) 0,45 s



(d) 0,30 s



(e) 0,25 s



(f) 0,20 s

Figure 2: light micrographs of the cavities generated in human enamel surface and respective shutter open times.

A theoretical model for temperature calculation in dental enamel irradiated by several laser pulses are being carried out in order to estimate the temperature variation at the end of the observed exposure threshold time and will be opportunely published. It is expected that this theoretical estimative corroborates the experimental evidences and help to reach a more comprehensive knowledge of laser-tissue interaction mechanisms.

4. CONCLUSION

Cavities were generated in human dental enamel without the use of photo-absorbers by the green line of the Cu-HBr laser and several exposure times. From light micrographs, surface damage on dental enamel samples was evaluated and an exposure time threshold was determined. Experimental evidences suggest that the ablation process is thermal due to the overlap of consecutive laser pulse energy deposition at the same spot in a short time interval.

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